NCELA
National Clearinghouse for English Language Acquisition and Language Instruction Educational Programs

RESOURCES FOR PREPARING TEACHERS OF SCIENCE AND MATHEMATICS TO WORK WITH ENGLISH LEARNERS

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Scientists don't memorize the periodic table. Scientists solve problems ... We need to make science cool again. **Astronaut Sally Ride, quoted in *The Washington Post*, February 9, 2011**

A number of current initiatives from the White House and the U.S. Department of Education emphasize the pressing need to increase America's capacity in the fields of science, technology, mathematics, and engineering (STEM). This document is intended to be a resource to educators working in science and mathematics education with the approximately 5.3 million children in US schools who are currently classified as English learners (ELs).[1] The document first presents a short summary of research findings and best practices emerging from the literature on ELs and science and mathematics. It then goes on to briefly outline the pressing need for an increased focus on science and mathematics education for this population of learners, highlighting both achievement gaps in current school performance as well as the need for a diverse workforce with skills in STEM fields. The remainder of the document lists relevant literature assembled to be of use to teachers, principals, school administrators, teacher educators, and others working toward effective science and mathematics education for English learner students. The resources are split into two sections: *Practitioner Resources* are intended primarily to inform instruction for classroom teachers, while *Program Development Resources* summarize research and outline best practices for professional development programs.

Summary of Research & Practice Literature

A number of common themes emerge from the research and practice literature on ELs and science/mathematics education.

- Ongoing and effective professional development is crucial. Many content-area teachers of science and mathematics have not been prepared to work effectively with EL students.
- Teachers of mathematics and of science require professional development that is tailored specifically to pedagogical content knowledge in their content area. As well as broad knowledge about EL students, they also need particular knowledge about the needs of ELs in math and the needs of ELs in science.
- Culturally competent instruction in which cultural diversity is viewed as an asset rather than a deficit supports the learning of EL students.
- Effective science and math education for ELs builds on the knowledge that students bring to the classroom and effective teachers of ELs are able to create lessons based on that background knowledge.
- ELs need support with the academic language of science and mathematics.
- In the domain of written language, ELs need support in the conventions of writing in science as well as in the comprehension of written problems in mathematics.
- In the domain of oral language, ELs need to be included in scientific conversations with their peers in order to participate fully in inquiry-based science classrooms where critical thinking flourishes.

[1] NCELA (February 2011). *The growing numbers of English Learner Students, 1998/99-2008/09,* available from http://www.ncela.gwu.edu/files/uploads/9/growingLEP_0809.pdf. The U.S. Department of Education reports about 4.7 million ELs in the country; see May 2010 report available from http://www2.ed.gov/rschstat/eval/title-iii/behind-numbers.pdf. NCELA and USDE numbers are based on the *Consolidated State Performance Reports* completed by states each year; however, NCELA includes the outlying entities (e.g., the Federated States of Micronesia, the Virgin Islands) and uses a different method to identify the number of EL students in the Commonwealth of Puerto Rico.

Why focus on science and mathematics for English learners?

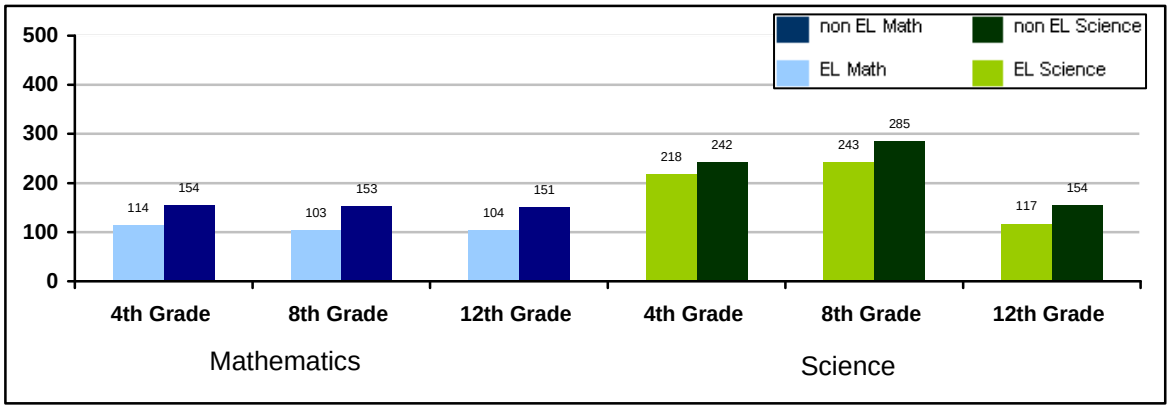
As the United States approaches a majority-minority demographic, the diversity of the US population represents a key competitive edge in the labor market. The ability to apply multiple perspectives to solving the scientific and engineering problems of infrastructure, manufacturing, and medicine, as well as the challenges of ecology and the environment, requires that people from all walks of life contribute to the scientific life of the nation. Numerous studies of the corps of working scientists, however, have found that under-representation of women and minorities in the sciences continues (Bayer, 2010; Congressional Commission on the Advancement of Women and Minorities in Science, Engineering and Technology Development, 2000).

> Until our scientific and technological workplace reflects our diversity, we are not working to our potential as a nation.
>
> Congresswoman Constance A. Morella, quoted in *Land of Plenty: Diversity as America's Competitive Edge in Science, Engineering and Technology*

> When people bring a broad range of ideas, which are informed by diverse cultures, languages, and worldviews, to the question of how the natural world works, science can only be enriched. When people are asked to leave their cultures, languages, and ways of knowing behind in order to study the natural world, then science is impoverished (Lee & Buxton, 2010, p. 27).

This underrepresentation in the professional realm may be a consequence of in-school performance in tests of science. In the 2009 National Assessment of Educational Progress, English learners consistently scored lower than their fluent English-speaking peers[2] on tests of science and math.

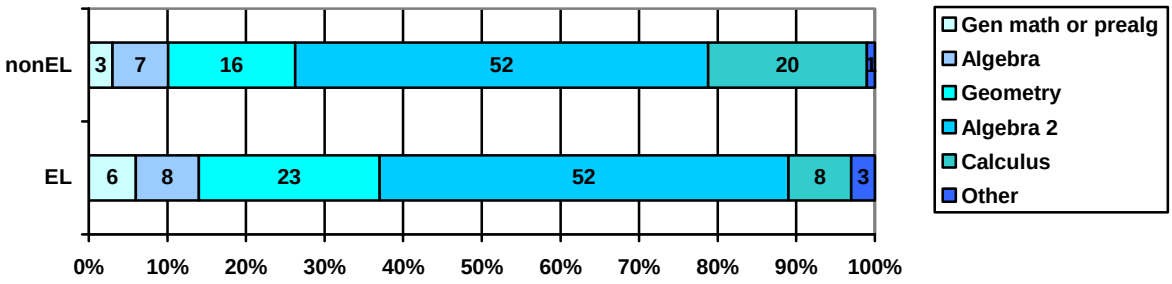
Figure 1. English learner and non-English learner results on the 2009 National Assessment of Educational Progress: Science and Mathematics



In the realm of mathematics, NAEP data also illustrate that ELs are taking less challenging courses than their fluent English-speaking peers (Wilde, 2010).

[2] NAEP defines "nonEL" as those students who are English proficient, including students who speak only English as well as students who have never been identified as EL even though they have a different home language, and students who were formerly identified as EL (Wilde, 2010).

Figure 2: Highest level math course taken, for 17-year-old EL and nonEL students, in 2008



Preparing content teachers to work with English learners

In order to rectify the gaps in both achievement and in higher-level courses, teachers of science and mathematics need to be more thoroughly prepared to teach these subjects in a way which connects with EL students. A key insight from educators working to prepare mainstream content teachers to work with ELs is that generic strategies for ELs cannot be applied across the content areas. Rather, teachers require specific pedagogical content knowledge to give them tools to work with ELs learning mathematics, or ELs learning science (Ballantyne, Sanderman & Levy, 2008). The imperative to ensure that all teachers of science and mathematics have the tools to work with ELs is reflected in the teacher education standards of the respective professional organizations for these disciplines.

The National Council of Teachers of Mathematics (NCTM) pedagogy standard 8.1. requires that the teacher:

> Selects, uses, and determines suitability of the wide variety of available mathematics curricula and teaching materials for all students including those with special needs such as the gifted, challenged, and speakers of other languages (NCTM, 2000).

The National Research Council's (NRC) *National Science Education Standards* state that:

> the commitment to science for all implies inclusion of those who traditionally have not received encouragement and opportunity to pursue science -- women and girls, students of color, students with disabilities, and students with limited English proficiency (NRC, 1996).

The National Science Teachers Association furthermore calls for teacher education that focuses on science content and pedagogy for ELs; high-quality instruction that meets the needs of ELs; educational policies that support the needs of ELs learning science; and educational research that promotes science learning for EL students (from the *Position Statement of the National Science Teachers Association: Science for English Learners*—see appendix for a fuller extract.)

The resources that follow are designed to support educators working to provide effective science and mathematics education for English learners. The first section, *Practitioner Resources*, divides resource by those relevant mainly to teachers of mathematics and those relevant mainly to teachers of science. The resources in this section are intended to be of use to classroom teachers seeking instructional strategies grounded in research. The second section, *Program Development Resources*, is intended to inform educators in creating and maintaining professional development programs. The resources in this section encompass both selected primary research papers that inform the practitioner resources, as well as descriptions of the implementation of professional development programs.

References

Ballantyne, K.G., Sanderman, A.R., Levy, J. (2008). *Educating English language learners: Building teacher capacity*. Washington, DC: National Clearinghouse for English Language Acquisition. Available from http://www.ncela.gwu.edu/files/uploads/3/EducatingELLsBuildingTeacherCapacityVol1.pdf .

Congressional Commission on the Advancement of Women and Minorities in Science, Engineering and Technology Development. (2000). *Land of Plenty: Diversity as America's Competitive Edge in Science, Engineering and Technology*. Washington, DC: Author. Available from http://www.nsf.gov/pubs/2000/cawmset0409/cawmset_0409.pdf

Bayer (2010). Bayer Facts of Science Education XIV: Female and Minority Chemists and Chemical Engineers Speak about Diversity and Underrepresentation in STEM. Bayer Corporation. Available from http://bayerfactsofscience.online-pressroom.com/

Lee, O., & Buxton, C.A. (2010). *Diversity and Equity in Science Education: Research, Policy, and Practice*. Columbia University, NY: Teachers College.

National Research Council. (1996). National science education standards. Washington, DC: National Academy. Available from http://www.nap.edu/readingroom/books/nses/

National Council of Teachers of Mathematics. (2000). Principles and standards for school mathematics. Reston, VA: Author. Available from http://standards.nctm.org/

Wilde, J. (May 2010). Comparing results of the NAEP Long-Term Trend Assessment: ELLs, former ELLs, and English-proficient students. Paper presented at the annual meeting of the American Educational Research Association, Denver, CO. Available from http://www.ncela.gwu.edu/files/uploads/16/AERA_2010_Wilde.pdf

Practitioner Resources

AccELLerate! 2.1 (Fall 2009) Special issue on *Math and Science Literacy for English Language Learners* Includes:

- Chilton & Martin: "Equals" is the Point: A Perspective on Math Instruction for English Language Learners
- Freeman & Crawford: Embedded Instructional Support in Math Content
- Kennedy: Using Open Source Software to Connect Science, Technology, English, and Math for English Language Learners
- Kopriva: Assessing the Skills and Abilities in Math and Science of English Language Learners with Low English Proficiency: A Promising New Method
- Powers & Stansfield: Developing Science Literacy for English Language Learners
- Wilde: NAEP, the "Nation's Report Card," and ELL Student-Mathematics

Available from: http://www.ncela.gwu.edu/files/uploads/17/Accellerate_2_1.pdf

Resources for Science Teachers

Anstrom, K. (1998). *Preparing secondary education teachers to work with English language learners: Science*. NCBE Resource Collection Series, No. 11. Available from http://www.ncela.gwu.edu/files/rcd/BE020886/Preparing_Secondary_Education_.pdf

This document examines the education of secondary level ELs within mainstream science classes. It provides teachers and teacher educators with an understanding of how mainstream science instruction can be designed and implemented to enhance academic achievement for these students. Research for this report included an extensive search of various databases and World Wide Web sites; analysis of the national content standards documents for science and three other core areas; site visits to a suburban high school that used a team teaching approach to working with ELs enrolled in mainstream classes; and personal interviews with education faculty at The George Washington University who are responsible for preparing preservice teachers for secondary level mainstream instruction. After an introduction, the first section discusses National Science Education Standards and the EL, focusing on: involving students in scientific inquiry; advocating for a less-is-more curriculum; teaching the language of science; making oral and written language comprehensible; teaching problem solving and learning strategies; using appropriate assessment; and using a three-tiered approach to science instruction for ELs. The second section discusses the preparation of mainstream teachers to work with EL students.

August, D., Artzi, L., & Mazrum, J. (2010) *Improving Science and Vocabulary Learning of English Language Learners*. CREATE Brief. Washington, DC: Center for Research on the Educational Achievement and Teaching of English Language Learners. Available from http://www.cal.org/create/resources/pubs/CREATEBrief_AcademicLanguage.pdf

This brief report first reviews the research on effective science instruction for English learners, with a focus on hands-on science instruction and on instruction that embraces the cultural and

linguistic background knowledge of these students. The authors also summarize the literature on English language proficiency and science proficiency, noting the powerful role of cognates in building English vocabulary. Two interventions are described; both improved the science vocabulary of the test group but the second was more effective and also built science content knowledge.

Ballantyne, K.G., Sanderman, A.R., & Levy, J. (2008). Science. Excerpt from *Educating English language learners: Building teacher capacity*. Washington, DC: National Clearinghouse for English Language Acquisition. Available from http://www.ncela.gwu.edu/files/uploads/3/scienceforELLs.pdf

This short three-page handout provides practical hands-on information that teachers of science can implement in the classroom, as well as resources for further reading and research that teachers can investigate in professional learning communities.

Carr, J., Sexton, U., & Lagunoff, R. (2006). *Making science accessible to English learners: A guidebook for teachers.* San Francisco: WestEd.

This guidebook is designed for middle and high school science teachers who are looking for practical ways to help EL students in their classrooms understand the rigorous science content reflected in state standards. Science teachers at the elementary school level should also find the strategies in this guidebook relevant and useful, although the content of specific examples do not always reflect elementary school standards. The guidebook is meant for use in conjuction with district textbooks and other materials and within a program of teacher support that includes professional development, collegial discussions, and coaching.

Edmonds, L.M. (March 2009). Challenges and Solutions for ELLs: Teaching Strategies for English Language Learners' Success in Science. *The Science Teacher*; 30-33.

This article describes some of the difficulties ELs may have with science content and offers techniques teachers can use to facilitate student understanding and participation. The article is based on the literature, the author's own classroom research, research from the Secondary Teacher Education and Professional Training for ELLs program, and the author's experience running an afterschool science program for high school ELs. The challenges discussed are: (1) relating to American ways of perceiving the sciences; (2) understanding what is being taught in the classroom; (3) using academic language to discuss scientific concepts; (4) participating in class discussion; and (5) writing appropriate scientific academic texts.

Fathman, A. K. & Crowther, D. T. (Eds.). (2006). *Science for English language learners: K-12 classroom strategies.* Arlington, VA: National Science Teachers Association.

This book is for teachers, prospective teachers, and teacher educators. Its purpose is to provide educators with a guide for teaching science to EL students. By using this book, educators will develop experience in teaching science content and processes, in language and literacy development, and in inquiry-based teaching, while getting practical ideas for teaching. The book describes instructional practices in science and language, describes effective teaching strategies, provides models for lesson and curriculum development, and gives an overview of standards development and implementation.

Gagnon, M.J. & Abekkm S.K. (Jan 2009). ELLs and the Language of School Science. *Science and Children*; 50-51.

This article draws on advice from research to answer the following questions: (1) What challenges do ELs face while learning science?; (2) How can ELs develop scientific understanding through science talk?; (3) How do ELs benefit from inquiry-based science instruction?; and (4) What strategies are effective in helping ELs develop the language of school science? This last section discusses sheltered instruction.

Gomez, K. & Madda, C. (1995). Vocabulary Instruction for ELL Latino Students in the Middle School Science Classroom. *Voices from the Middle, 13*(1), 42-47.

Many teachers find themselves working with ELLs in content-area classes without the arsenal of tools and training that will help them help their students. This is a recounting of how one teacher, with the help of thoughtful observers and a commitment to teaching all of her students, worked to create strategies that improved language learners' English, science vocabulary, and content understanding. [author's abstract]

Himmel, J. & Short, D.J. (2009). *Using the SIOP Model to Improve Middle School Science Instruction. CREATE Brief*. Washington, DC: Center for Research on the Educational Achievement and

Teaching of English Language Learners. Available from http://www.cal.org/create/resources/pubs/CREATEBrief_SIOPScience.pdf

Provides some practical examples of ways in which teachers can use sheltered instruction--specifically the Sheltered Instruction Observational Protocol--to present science concepts in ways that are meaningful to ELs. A mini-lesson on vocabulary illustrates how a teacher can provide students with multiple opportunities to use new vocabulary words. The authors provide an example of a small group activity that encourages interaction and science talk among students. Finally, a template for review and assessment is outlined.

Jarrett, D. (1999). The inclusive classroom: Teaching mathematics and science to English language learners. Portland, OR: Northwest Regional Educational Laboratory. Available from http://www.eric.ed.gov/PDFS/ED455690.pdf

This publication aims to help teachers more effectively teach math and science to ELs. It argues that the learner's home language can play an important role in his or her science and math learning, whether or not the teacher speaks that language. When students are allowed to use their home language in the classroom, their academic performance improves, which can help them to build a solid foundation in math and science concepts before entering the higher grades where language becomes more decontextualized and cognitively demanding. Skills in content areas like math and science, once learned in the first language, are retained when instruction shifts to the second language. The book is divided into several sections including the following: "Understanding the Specialized Languages of Mathematics and Science;" "Linking Second Language Strategies with Content Instruction;" "Thematic Instruction;" "Cooperative Learning;" "Inquiry and Problem Solving;" "Vocabulary Development;" "Classroom Discourse;" "Affective Influences;" "Assessment;" "Collaborating with Other Teachers;" " and "Involving the Family." There are also three "scenes for the classroom," where practicing teachers share what has worked well for them in their classrooms. [ERIC abstract]

Lee, O. & Buxton, C.A. (2010). *Diversity and Equity in Science Education: Research, Policy, and Practice*. Columbia University, NY: Teachers College.

Two leading science educators provide a comprehensive, state-of-the-field analysis of current trends in the research, policy, and practice of science education. This book offers valuable insights into why gaps in science achievement among racial, ethnic, cultural, linguistic, and socioeconomic groups persist, and points toward practical means of narrowing or eliminating these gaps. Lee and Buxton examine instructional practices, science-curriculum materials (including computer technology), assessment, teacher education, school organization, federal and state policies, and home-school connection. The book features: a synthesis of the emerging body of research in the field of science education and its application to practice and policy; a description of effective practices for narrowing science achievement gaps among demographic subgroups of students; a focus on the unique learning needs of English language learners; and an analysis of major science education initiatives, interventions, and programs that have been successful with nonmainstream students. [adapted from publisher's blurb]

Pray, L. & Monhardt, R. (March 2009). Sheltered instruction techniques for ELLs: Ways to adapt science inquiry lessons to meet the academic needs of English language learners. *Science and Children* 34-38.

This article offers suggestions to adapt science instruction for ELs based on the concept of sheltered instruction, a model of language-support methods derived primarily from the Sheltered Instruction Observational Protocol (SIOP). The article describes planning an inquiry-based lesson on magnets using the following steps: (1) determine skills and concepts; (2) incorporate background knowledge; (3) select teaching/learning experiences (including how critical vocabulary with be introduced and developed, how students will meaningfully interact, and what kinds of instructional strategies will be helpful); and (4) assess student knowledge.

Resources for Math Teachers

The Texas State University System Math for English Language Learners Project (http://www.tsusmell.org/) has a wealth of useful techniques and tips for math teachers.

The Connected Mathematics project at Michigan State University has a page on mathematics and ELs at http://connectedmath.msu.edu/teaching/ell.html

Long Beach Unified Schools District maintains a list of cognate mathematics vocabulary in English and Spanish http://www.lbschools.net/Main_Offices/Curriculum/Areas/Mathematics/XCD/ListOfMathCognates.pdf

Southwest Educational Development Laboratory (SEDL) pages on *What can a mathematics teacher do for the English language learner?* at http://txcc.sedl.org/resources/mell/index.html provide strategies for teachers working with students at different levels of English language proficiency.

Anstrom, K. (1999). Preparing secondary education teachers to work with English language learners: Mathematics. *NCBE resource collection series*, no. 14. Available from http://www.ncela.gwu.edu/files/rcd/BE020889/Preparing_Secondary_Education_.pdf

This report, the fourth in a series, integrates findings from research pertaining to content area instruction of linguistically and culturally diverse learners. The focus is on the education of secondary-level ELs within mainstream mathematics classes. The intent of this document is to give teachers and teacher educators a better understanding of how mainstream mathematics instruction can be designed and implemented to enhance academic achievement and learning for these students. Research for this report included an extensive search of online databases and websites for information regarding effective curriculum and instruction, content standards, student assessment, teacher training, and education.

Ballantyne, K.G., Sanderman, A.R., & Levy, J. (2008). Mathematics. Excerpt from *Educating English language learners: Building teacher capacity*. Washington, DC: National Clearinghouse for English Language Acquisition. Available from http://www.ncela.gwu.edu/files/uploads/3/mathforELLs.pdf

This short three-page handout provides practical hands-on information that teachers of mathematics can implement in the classroom, as well as resources for further reading and research that teachers can investigate in professional learning communities.

Carr, J., Sexton, U., Lagunoff, R., Carroll, C., Cremer, S., & Gale, M. (2009). *Making Mathematics Accessible to English Learners: A Guidebook for Teachers, Grades 6-12*. San Francisco: WestEd.

This practical book helps upper elementary, middle, and high school mathematics teachers effectively reach ELs in their classrooms. Designed for teachers who have had limited preparation for teaching mathematics to ELs, the guide offers an integrated approach to teaching mathematics content and English language skills, including guidance on best instructional practices from the field, powerful and concrete strategies for teaching mathematics content along with academic language, and sample lesson scenarios that can be implemented immediately in any mathematics class. It includes: rubrics to help teachers identify the most important language skills at five English language development (ELD) levels; practical guidance and tips from research and the field; seven scaffolding strategies for differentiating instruction; seven tools to promote mathematical language; assessment techniques and accommodations to lower communication barriers for ELs; and three integrated lesson scenarios demonstrating how to combine and embed these various strategies, tools, techniques, and approaches. Chapter topics include teaching inquiry-based mathematics, understanding first and second language development, teaching the language of mathematics, scaffolding mathematics learning, and applying strategies in the classroom.

Christian, J. & Coulter, C.A. (2008). Chapter 5 *Teaching English learners and immigrant students in secondary schools*. Upper Saddle River, NJ: Pearson Education, Inc.

Current research-based teaching and learning principles are the foundations for establishing academic communities and creating identity with second language learners. The authors provide extensive information on setting up effective and successful programs for immigrant students in secondary schools. The first section presents the historical background of educational policy in regards to ELs and bilingual education. The second section focuses on various content area subjects such as Language Arts, Math, Social Studies, and Science. For each content area, the authors discuss how to create a community of learners, foster collaboration and integrate English language development. Classroom vignettes are included to give the reader concrete examples of strategies and activities successfully implemented in classrooms with immigrant students. The last section covers the issues of assessing ELs in content area classes and for program identifi-

cation and classification. Reflection and questions are interspersed throughout the text that provide an opportunity to make connections with the text.

Dale, T. C. & Cuevas, G. J. (1987). Integrating mathematics and language learning. In J. A. Crandall (Ed.), *ESL through content-area instruction: Mathematics, science, social studies* (pp. 9-54). Englewood Cliffs, NJ: Prentice Hall Regents.

Dale and Cuevas, drawing on extensive research and teaching experiences, recognize the challenge that mathematics can be for ELs. They do not subscribe to the myth that mathematics is numbers and not language; therefore, ELs will do fine in math classes. They clarify language issues specific to mathematics and describe how everyday vocabulary takes on math-specific meanings in the math classroom. They discuss the abstract nature of math and describe some common mistakes made by ELs in math classes. They do an excellent job explaining the language skills needed for math learning. The authors provide extensive specific suggestions on how to encourage language development in the mathematics classrooms.

Nelson-Barber, S. & Lipka, J. (2008). Rethinking the case for culture-based curriculum: Conditions that support improved mathematics performance in diverse classrooms. In M.E. Brisk (Ed.), *Language, Culture and Community in Teacher Education* (pp. 99-126). New York: Lawrence Erlbaum Associates.

This description of a successful mathematics semester in a school in Alaska illustrates what a culture-based curriculum looks like in practice. Math lessons are based on traditional fishing practices. Students' traditional indigenous knowledge of fishing practices from the starting point to the unit *Drying Salmon*. The lessons integrate the mathematical skills of measuring, estimating, proportional thinking and algebra as part of a single thematic math unit.

Secada, W. G., Ortiz-Franco, L., Hernandez, N.G., & De La Cruz, Y. (Eds.) (2000). *Changing the faces of mathematics: Perspectives on multiculturalism and gender equity*. Reston, VA: National Council of Teachers of Mathematics.

This volume of a six-volume series discusses issues and highlights successful equity practices. The book relates equity to issues of systemic reform, access to technology, definitions of culture and multiculturalism, tracking, assessment, parent involvement, teacher education and attitudes of math teachers. It also includes ideas of culturally responsive curricular and instructional strategies, with special attention devoted to the integration of multicultural textbooks into early-grades math. Also presented are a feminist epistemology in math, and a cognitive analysis of language issues and their relationship to assessment.

Stepanek, J. (2004). From Barriers To Bridges: Diverse Languages in Mathematics and Science. *Northwest Teacher*, *5*(1), 2–5. http://educationnorthwest.org/webfm_send/344

This resource focuses on the language of mathematics and on ways in which teachers can draw upon students' existing background knowledge to build a mathematics vocabulary. Examples of the number system from various languages are presented, as well as techniques to connect the specialized vocabulary of mathematics with students' everyday vocabulary.

Program Development Resources

(NOTE: Many of the resources below were contributed by participants in the 2008 NCELA Roundtable on Professional Development, and included in the NCELA publication *Educating English language learners: Building teacher capacity*.)

Amaral, O. M., Garrison, L., & Klentschy, M. (2002). Helping English learners increase achievement through inquiry-based science instruction. *Bilingual Research Journal*, 26(2), 213-239.

The study examined the impact of a four-year professional development intervention in promoting science and literacy with predominantly Spanish-speaking elementary students as part of a district-wide local systemic reform initiative in a rural school district. The study found that the longer students participated in the intervention classes, the higher they scored in tests of science, writing, reading, and math. The five areas of emphasis in this NSF-supported, district-wide local systemic reform initiative included high quality curriculum, sustained professional development and support for teachers and school administrators, materials support, community and top-level administrative support, and program assessment and evaluation. The inquiry-based science pro-

gram started with 14 pioneer, volunteer teachers from two school sites. As the program progressed, more teachers and sites were added to the program until the program became available to all teachers at all elementary schools in the school district. Over four years, teachers were provided with at least 100 hours of professional development designed to deepen their understanding of science, address pedagogical issues, and prepare them to teach science at their grade level. Teachers also received in-classroom professional support from a cadre of resource teachers, and complete materials and supplies for all the science units.

Ballenger, C. & Rosebery, A. S. (2003). What counts as teacher research? Investigating the scientific and mathematical ideas of children from culturally diverse backgrounds. *Teachers College Record, 105*(2), 297-314.

The study explored a particular approach to teacher research, based in teachers' concerns for underachieving students, particularly those from non-mainstream backgrounds. They report on a conference where experienced teachers from existing teacher research groups met with new teachers to explore classroom data together. The conference was structured around joint exploration of children's classroom talk and work, with particular attention to the talk and work of "puzzling children," i.e., those a teacher finds difficult to understand. The experienced teacher researchers showed how close observation of children can challenge taken-for-granted assumptions about children's talk and work. They also demonstrated that children who make puzzling responses do not necessarily have deficient ideas, but rather are operating from a framework different from the one commonly assumed.

Buck, G., Mast, C., Ehlers, N., & Franklin, E. (2005). Preparing teachers to create a mainstream science classroom conducive to the needs of English-language learners: A feminist action research project, *Journal of Research in Science Teaching*, 42(9), 1013-1031.

A feminist action research team, which consisted of a science educator, an EL educator, a first-year science teacher, and a graduate assistant, set a goal to work together to explore the process a beginning teacher goes through to establish a classroom conducive to the needs of middle-level ELs. The guiding questions of the study were answered by gathering a wealth of data from the classroom, planning sessions, and researchers and students over the course of five months. These data were collected by observations, semi-structured interviews, and written document reviews. The progressive analysis ultimately revealed that: (a) successful strategies a beginning teacher must utilize for teaching middle-level EL children in a mainstream classroom involve complex structural considerations that are not part of the teacher's preparation; (b) learning increases for all children, but there are differences in learning achievement between EL and non-ELL children; and (c) student and peer feedback proved to be an effective means of enhancing the growth of a beginning teacher seeking to increase her skills in teaching ELs. [from author's abstract]

Buxton, C., Lee, O., & Santau, A. (2008). Promoting science among English language learners: Professional development for today's culturally and linguistically diverse classrooms. *Journal of Science Teacher Education 19*(5) 495-511.

This article describes a model professional development intervention currently being implemented to support third through fifth grade teachers' science instruction in nine urban elementary schools with high numbers of ELL students. The intervention consists of curriculum materials for both students and teachers, as well as teacher workshops throughout the school year. The curriculum materials and workshops are designed to complement and reinforce each other in improving teachers' knowledge, beliefs, and practices in science instruction and English language development for ELs. In addition to these primary goals, secondary goals of the intervention include supporting teachers' and students' mathematical understanding, improving teachers' and students' scientific reasoning, capitalizing on students' home language and culture, and preparing students for high-stakes science testing and accountability through hands-on, inquiry-based learning experiences. [from author's abstract]

Fradd, S. H. & Lee, O. (1995). Science for all: A promise or a pipe dream for bilingual students? *Bilingual Research Journal, 19,* 261-278.

The study examined teachers' perceptions of science instruction at two elementary schools, one suburban and one urban, each with high percentages of EL students. It was conducted through formal and informal interviews with teachers. The results indicated that teachers in both schools viewed science instruction positively, expressed beliefs that all students could learn sci-

ence, and stressed that science learning opportunities should be available to all students. They also agreed on the importance of active student engagement, practical applications in daily life, and authentic and meaningful tasks. They emphasized the need to promote language development during science instruction for all students. Despite these similarities, the two schools displayed clear contrasts in terms of teachers' ideas about opportunities and resources for science learning and the instructional environment in each school setting. The urban school teachers perceived students' limited English proficiency and cultural difference as reasons for their difficulties in learning science. The teachers were not specific about instruction or articulate about their own beliefs regarding effective instructional approaches. In contrast, the suburban schoolteachers generally promoted science learning along with English language skills more effectively than those at the urban school (although it should be recognized that EL students at the suburban school were likely to have better academic skills in the home language than those at the urban school). However, even under these more favorable conditions, the suburban teachers missed opportunities to promote student learning, as their science instruction tended to involve discrete science activities rather than being organized around a comprehensive science program.

Hampton, E. & Rodriguez, R. (2001). Inquiry science in bilingual classrooms. *Bilingual Research Journal*, 25(4), 461-478.

The study implemented a hands-on, inquiry science curriculum (i.e., the Full Option Science Series, FOSS) with Spanish-speaking elementary children who were developing English fluency along with their first language skills. Study participants, who included university interns, classroom teachers, and elementary students, gave strong positive responses concerning the value of this inquiry approach for increasing the children's understanding of science concepts in both languages. This curriculum was used in a science teacher preparation program and the university interns, in turn, taught science using this curriculum to K-5 grade students in 62 classrooms at three elementary schools near the U.S.-Mexican border. They taught six one-hour lessons over the course of six weeks, with half of the instruction in Spanish and half in English. One written assessment, containing three inquiry items and three open-ended response items about the Foods and Nutrition unit, was administered to 107 students in 5th grade. The four-page written assessment was available to the students in Spanish or English, and they could respond in the language of their choice. Of these students, 55% chose to respond in Spanish and 45% responded in English. Correct performance ranged from about 33% to 51% across the six items. There was relatively little difference between children who chose to respond in Spanish and those who chose to respond in English. Additionally, participants' perceptions were examined from multiple data sources, including university interns via written comments and focus group interviews, in-service teachers via an attitude survey and written comments, and 80 students in 3rd grade via an attitude survey.

Lee, O. (2005). Science education and English language learners: Synthesis and research agenda. *Review of Educational Research, 75*(4), 491-530.

This review analyzes and synthesizes then-current research on science education with ELLs. Science learning outcomes with ELs are defined in the context of equitable learning opportunities. Then, the literature on science education with ELs is discussed with regard to science learning, science curriculum (including computer technology), science instruction, science assessment, and science teacher education. Science education initiatives, interventions, or programs that have been successful with ELs are highlighted. Conclusions with regard to key features (e.g., theoretical perspectives and methodological orientations) and key findings in the literature are offered. Finally, a research agenda is proposed to strengthen those areas in which the need for a knowledge base is most urgent, as well as those that show promise in establishing a robust knowledge base.

Lee, O. & Fradd, S. H. (1998). Science for all, including students from non-English language backgrounds. *Educational Researcher, 27*(3), 12-21.

Standards-based reform across subject areas has an overarching goal of achieving high academic standards for all students. Although much is known about what constitutes high academic standards, little attention has been given to the attainment of educational equity for all students. This article proposes the notion of *instructional congruence* as a way of making academic content accessible, meaningful, and relevant for diverse learners. Although the discussion considers English language learners in science education, comparable approaches can be applied to other di-

verse student groups and other subject areas. An agenda for promoting research, practice, and policy in promoting high standards for all students across subject areas is discussed.

NOTE: The following list of studies by Lee and colleagues is presented in conceptual order and described in one combined annotation.

Lee, O. (2004). Teacher change in beliefs and practices in science and literacy instruction with English language learners. *Journal of Research in Science Teaching, 41*(1), 65-93.

Lee, O., Hart, J., Cuevas, P., & Enders, C. (2004). Professional development in inquiry-based science for elementary teachers of diverse students. *Journal of Research in Science Teaching, 41*(10), 1021-1043.

Hart, J. & Lee, O. (2003). Teacher professional development to improve science and literacy achievement of English language learners. *Bilingual Research Journal 27*(3), 475-501.

Lee, O., Luykx, A., Buxton, C. A., & Shaver, A. (2007). The challenge of altering elementary school teachers' beliefs and practices regarding linguistic and cultural diversity in science instruction. *Journal of Research in Science Teaching, 44*(9), 1269-1291.

Lee, O., Deaktor, R., Enders, C., & Lambert, J. (2008). Impact of a multi-year professional development intervention on science achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching.*

Lee, O., Deaktor, R. A., Hart, J. E., Cuevas, P., & Enders, C. (2005). An instructional intervention's impact on the science and literacy achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching, 42*(8), 857-887.

Cuevas, P., Lee, O., Hart, J., & Deaktor, R. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching, 42*(3), 337-357.

Lee, O., Buxton, C. A., Lewis, S., & LeRoy, K. (2006). Science inquiry and student diversity: Enhanced abilities and continuing difficulties after an instructional intervention. *Journal of Research in Science Teaching, 43*(7), 607-636.

Lee, O., LeRoy, K., Thornton, C., Adamson, K., Maerten-Rivera, J., & Lewis, S. (2008). Teachers' perspectives on a professional development intervention to improve science instruction among English language learners. *Journal of Science Teacher Education 19*(1), 41-67.

Lee, O., Lewis, S., Adamson, K., Maerten-Rivera, J., & Secada, W. G. (2007). Urban elementary school teachers' knowledge and practices in teaching science to English language learners. *Science Education.*

Lee, O., Maerten-Rivera, J., Penfield, R., LeRoy, K., & Secada, W. G. (2008). Science achievement of English language learners in urban elementary schools: Results of a first-year professional development intervention. *Journal of Research in Science Teaching.*

Lee (2004) examined patterns of change in elementary teachers' beliefs and practices as they learned to teach English language and literacy as part of science instruction through their three-year collaboration with the research team. Working with six bilingual Hispanic teachers of Hispanic students at two elementary schools, Lee described changes in teachers' beliefs and practices around literacy instruction. Teachers gradually learned to provide effective linguistic scaffolding, helped students acquire the conventions of standard oral and written English, and used multiple representational formats in oral and written communication. Overall, science instruction provided a meaningful context for English language and literacy development, while language processes provided the medium for understanding science.

As an expansion of Lee (2004), Lee and colleagues implemented similar, but less intensive, professional development intervention with all 3rd, 4th, and 5th grade teachers (over 75) from six elementary schools serving students from diverse linguistic and cultural backgrounds. They examined the impact of the intervention on each of the three domains: (a) inquiry-based science, (b) English language and literacy, and (c) students' home language and culture. In the first domain involving science instruction, after one-year participation in the intervention, the teachers reported significantly enhanced knowledge of science content and stronger beliefs about the importance of science instruction with EL students, although their actual practices did not show statistically significant change (Lee, Hart, Cuevas, & Enders, 2004). In the second domain involving the integration of English language and literacy development as part of science instruction, teachers came to place greater emphasis on the importance of reading and writing in science instruction, express a broader and more integrated conceptualization of literacy in science, and provide more

effective linguistic scaffolding to enhance scientific understanding (Hart & Lee, 2003). In the third domain involving incorporation of students' home language and cultural experiences in science instruction, teachers rarely incorporated students' home language or culture into science instruction, as they began their participation in the intervention. During the two-year period of the intervention, teachers' beliefs and practices remained relatively stable and did not show significant change (Lee, Luykx, Buxton, & Shaver, 2007).

Beyond examining the impact of the professional development intervention on teachers' beliefs and practices, Lee and colleagues also examined its impact on student outcomes. For 3rd, 4th, and 5th grade students over the three-year period of the intervention, significance tests of mean scores between pre- and posttests indicated statistically significant increases each year on all measures of project-developed science tests at all three grade levels (Lee, Deaktor, Enders, & Lambert, 2008). Achievement gaps among demographic subgroups sometimes narrowed among 4th grade students and remained consistent among 3rd and 5th grade students. Item-by-item comparisons with NAEP and TIMSS samples indicated overall positive performance by students at the end of each school year. Similar patterns of increased achievement gains and narrowing of achievement gaps were found in literacy (writing) outcomes (Lee, Deaktor, Hart, Cuevas, & Enders, 2005). Specifically with regard to the ability to conduct science inquiry of a sample of 25 students in 3rd and 4th grade, paired samples *t*-tests results indicated that the intervention enhanced the students' inquiry ability, regardless of demographic backgrounds. Particularly, low achieving, low SES, and ESOL-exited students made impressive gains (Cuevas, Lee, Hart, & Deaktor, 2005). More detailed analysis indicated that although these students demonstrated enhanced abilities with some aspects of the inquiry task, they continued to have difficulties with other aspects of the task even after instruction (Lee, Buxton, Lewis, & LeRoy, 2006). Confirming the results by Cuevas et al. (2005), while students from all demographic subgroups showed substantial gains, students from non-mainstream and less privileged backgrounds in science showed higher gains in inquiry abilities than their more privileged counterparts.

The results of the above series of studies by Lee and colleagues indicated teachers' overall receptiveness to the intervention as well as its relative strengths and weaknesses with regard to the professional development goals. The results also indicated the positive impact of the intervention on students' achievement outcomes and on narrowing of achievement gaps among demographic subgroups. ELL students demonstrated statistically significant gains in science and literacy (writing) achievement and enhanced abilities to conduct science inquiry. Especially, bilingual Spanish/English speaking students and those who exited from ESOL programs showed achievement outcomes that were comparable to or higher than those monolingual English-speaking students, thus narrowing achievement gaps. Given that the research included all 3rd, 4th, and 5th grade teachers within the six participating schools, rather than a self-selected group of volunteer teachers with an interest in "teaching science for diversity," their beliefs and practices may be more representative of teachers in general. Thus, the results have implications for further large-scale implementation (i.e., scaling up) of the intervention with diverse student groups in urban school districts.

In their current research, Lee and colleagues implement a professional development intervention that is aimed at improving science and literacy achievement of ELL students in urban elementary schools within the policy context increasingly driven by high-stakes testing and accountability across content areas, including science. The research tests two research questions: (1) can ELL students learn academic subjects, such as science, while also developing English proficiency? and (2) can ELL students, who learn to think and reason scientifically, also perform well on high-stakes testing? The research involves teachers from grades 3 through 5 and their students at 15 elementary schools in a large urban school district. All the schools enroll high proportions of ELL students and students from low socioeconomic status (SES) backgrounds, and have traditionally performed poorly according to the state's accountability plan.

At the end of the first-year of the five-year intervention, teachers believed that the intervention, through the provision of curriculum materials and teacher workshops, effectively promoted students' science learning along with English language development and mathematics learning (Lee, LeRoy, Thornton, Adamson, Maerten-Rivera, & Lewis, 2007). Teachers highlighted many strengths as well as areas needing improvement in the intervention, and the teachers' perspectives are incorporated into our on-going intervention efforts. Based on the first-year results using

a teacher questionnaire, classroom observations, and post-observation interviews, teachers' knowledge and practices in teaching science while supporting English language development of EL students were generally within the bounds supported by the intervention; however, such knowledge and practices fell short of the goal of reform-oriented practices (Lee, Lewis, Adamson, Maerten-Rivera, & Secada, 2007). Additionally, the research examined the impact of the intervention on science achievement of ELL students at the end of the first-year implementation (Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008). The study involved 1,134 students in 3rd grade at 7 treatment schools and 966 students in 3rd grade at 8 comparison schools. The results led to three main findings. First, treatment students displayed a statistically significant increase in science achievement. Second, students who were currently enrolled in ESOL programs (ESOL levels 1 through 4) performed comparably to students who had existed from ESOL or never been in ESOL. Third, treatment students showed a higher score on a statewide mathematics test, particularly on the measurement strand emphasized in the intervention, than comparison students. The results indicated that through our professional development intervention, EL students and others in the intervention learned to think and reason scientifically while also performing well on high-stakes testing.

Sato, E., Rabinowitz, S., Gallagher, C., & Huang, C. (2009). *Accommodations for English Language Learner Students: The Effect of Linguistic Modification of Math Test Item Sets. Final Report*. Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences http://ies.ed.gov/ncee/edlabs/regions/west/pdf/REL_20094079.pdf

This study examined the effect of linguistic modification (reducing the complexity of the language used) on middle school students' ability to show what they know and can do on math assessment. To do so, two item sets, each with 25 multiple-choice items, were developed, one containing original math items and one containing these items with linguistic modifications. The two sets were administered to three subgroups of students in grades 7 and 8: EL, non-English-language-arts (ELA)-proficient non-EL (NEP) students, and ELA-proficient non-EL (EP) students. In summary, findings suggested that: (1) EL, NEP, and EP differences in the effect of linguistic modification across 25 items measuring math understanding varied, depending on the scoring approach; (2) for each student subgroup, the mean difference in performance on the two item sets was greatest for EL students, followed by NEP students; (3) as implemented in the current study, linguistic modification did not alter the targeted math construct assessed; and (4) for all three student subgroups, one dominant factor (math understanding) was found to underlie both item sets; however, the measurement structure between the underlying factor and the items differed across student subgroups.

Secada, W. (1992). Race, ethnicity, social class, language, and achievement in mathematics. In D. Grouws (Ed.), *Handbook of research on math teaching and learning* (pp. 623-660). New York: Macmillan.

This review of the quantitative research lays out an intellectual agenda for scholarly research on the differential effectiveness of mathematics education based on social class, race, ethnicity, language background, and gender. The chapter discusses how we define diverse groups, mathematics achievement of these groups, and efforts to close the achievement gap. There is a relationship between the degree of English language proficiency and math achievement in English, with most EL students performing below native-speaker (NS) students. However, bilingualism (as opposed to Spanish-dominant, for example) is positively correlated to achievement. One of the great concerns is how research moves from description to prediction to causation. EL students are better off receiving instruction in their native language, which is positively correlated with mathematics achievement. Overall, the research casts differences in terms of individual ability, and demographic diversity and achievement are not addressed directly. Future work needs to focus on impact studies (not status studies), and reforms must be developed for the target groups, not for the overall student population.

Secada, W. G., Ortiz-Franco, L., Hernandez, N.G., & De La Cruz, Y. (Eds.) (2000). *Changing the faces of mathematics: Perspectives on multiculturalism and gender equity*. Reston, VA: National Council of Teachers of Mathematics.

This volume of a six-volume series discusses issues and highlights successful equity practices. The book relates equity to issues of systemic reform, access to technology, definitions of culture and multiculturalism, tracking, assessment, parent involvement, teacher education and attitudes

of math teachers. It also includes ideas of culturally responsive curricular and instructional strategies, with special attention devoted to the integration of multicultural textbooks into early-grades math. Also presented are a feminist epistemology in math, and a cognitive analysis of language issues and their relationship to assessment.

Stoddart, T., Pinal, A., Latzke, M., & Canaday, D. (2002). Integrating inquiry science and language development for English language learners. *Journal of Research in Science Teaching, 39*(8), 664-687.

As part of an NSF-supported local systemic initiative, the study involved 24 elementary schoolteachers of predominantly Latino EL students. The study found that after teachers participated in a professional development program, they had more elaborated conceptions of the relationship between inquiry-based science and language development. The thesis of this research is that inquiry-based science provides a particularly powerful instructional context for the integration of science content and second language development with EL students. Based on a conceptual framework for integrating English language development with inquiry-based science, the researchers developed a five-level rubric to assess teachers' understanding of science and ESOL integration. Then, based on interviews with the 24 teachers, they provide exemplars of teacher thinking at each level in the rubric. The preliminary analyses of teachers' work during the five-week summer professional development program indicate changes in teachers' understanding of science and language integration. Prior to their participation, the majority of teachers viewed themselves as well prepared to teach either science or language, but not both. After their participation in the professional development program, the majority of teachers believed they had improved in the domain in which they had initially felt less prepared.

Warren, B. & Rosebery, A. S. (1995). Equity in the future tense: Redefining relationships among teachers, students, and science in linguistic minority classroom. In W. G. Secada, E. Fennema, & L. B. Adajian (Eds.), *New directions for equity in mathematics education* (pp. 298-328). New York: Cambridge University.

As part of the ongoing Chèche Konnen Project, the study adopted a sociocultural view of teaching and learning in the description of how teachers practiced science as members of a scientific community. The researchers organized a seminar on scientific sense-making and worked with eight teachers, including five bilingual education teachers, two ESL teachers, and a science specialist. The teachers and the research team met every other week for two hours after school during the school year and for two weeks in the summer. They engaged in doing science as well as thinking about science as a discourse with particular sense-making practices, values, beliefs, concepts, objects, and ways of interacting, talking, reading, and writing. As they conducted scientific investigations around their own questions and shared their work with colleagues, the teachers learned to appropriate the discourse of science. They also felt that they succeeded in creating classroom communities in which students' scientific questions were valued, while they continued to reflect on ways to help shape students' questions into scientific investigations.

- Prepared by Keira G. Ballantyne, Assistant Director for Professional Development

Appendix
Extract from the Position Statement of the National Science Teachers Association: *Science for English Learners*

The full document (including references) can be found at: http://www.nsta.org/about/positions/ell.aspx

NSTA recommends that teacher preparation and professional development programs for teachers, regardless of area of certification, focus on science content and pedagogy for English language learners and help teachers

- recognize and build on ELL students' "funds of knowledge" (i.e., knowledge students gain from their family and cultural backgrounds) as a foundation for learning scientific ideas and practices (Moll 1992; Rodriguez and Berryman 2002);
- recognize that students who are learning English or who are from cultural and linguistic backgrounds different from the teachers' background may express what they know in ways that are unfamiliar to their teachers (Hudicourt-Barnes 2003; Warren et al. 2001);
- use instructional strategies that simultaneously promote science learning and English proficiency for English language learners (Amaral, Garrison, and Klentschy 2002; Genesee and Christian 2008; Lee et al. 2005; Thomas and Collier 2002); and
- meet regularly with fellow teachers to share ideas, experiences, tasks, and materials that are effective in teaching science to English language learners (Rosebery and Warren 2008).

High-quality science instruction should meet the learning needs of English language learners. NSTA recommends that science instruction

- provide students with academically rigorous learning opportunities that allow them to explore scientific phenomena and construct scientific understanding and inquiry based on their own linguistic and cultural experiences (Garcia & Lee 2008);
- provide students identified as English language learners with a meaningful learning environment in which to develop fluency in oral and written English as well as in the discourse of science. At the same time, improving English skills should provide the medium for understanding science content (Fathman and Crowther 2006; Lee and Fradd 1998; Rosebery, Warren, and Conant 1992);
- support learning opportunities in different classroom formats (e.g., individual, small-group, and whole-class instruction) so that students learn to work independently as well as collaboratively across varied settings; and
- incorporate effective instructional strategies to enable students who are learning English to access their prior knowledge, learn science content, and communicate science ideas by using multiple modes of representation (gestural, oral, pictorial, graphic, and textual).
- are academically rigorous and develop academic language in the context of learning science;
- incorporate experiences, examples, analogies, and values from diverse linguistic and cultural groups, and consider the knowledge and abilities that all students bring from their home and community cultures (Moll 1992; Garcia and Lee 2008); and
- include embedded assessments that take into account linguistic and cultural influences that affect ELL students' thinking and reasoning, as well as the ways that the students interpret and respond to assessment items (Solano-Flores and Nelson Barber 2001).

NSTA supports educational policies that meet the needs of ELL students learning science, including those that

- encourage states, districts, and schools to allocate resources for English language learners to learn rigorous science content and make adequate academic growth across successive years to reduce and close science achievement gaps;
- provide adequate time for science instruction for students identified as English language learners and reject the perceived notion that literacy and numeracy must be developed prior to science (Lee and Luykx 2005);
- allow or encourage the use of students' home language as an instructional support to promote science learning, even within an "English-only" policy (Goldenberg 2008; Garcia and Lee 2008); and
- make accommodations for English language learners to demonstrate their science knowledge separate from English proficiency or general literacy, such as conducting assessments and reading instructions in ELL students' home language in addition to English, providing separate testing environments and allowing more testing time (Abedi 2004; Solano-Flores 2008).

NSTA supports a research agenda that promotes science learning for students identified as English language learners. NSTA recommends that future research

- examine both the benefits and demands involved in learning science through inquiry by identifying how the essential aspects of inquiry-based teaching and learning relate to the linguistic and cultural experiences of English language learners;
- address student outcomes, including quantitative achievement data and other types of outcomes, in both science and literacy;
- examine how teachers' theories about students' knowledge base and instructional practices evolve as teachers reflect on ways to integrate these multiple domains to promote science learning and literacy development; and
- give high priority to examining the science-related "funds of knowledge" existing in diverse contexts and communities, such as how parents and community members can serve as valuable resources for school-based science learning, or the ability of community-based projects to help students recognize the relevance of science in everyday life.